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A Comparison of Monocular, Biocular, and Binocular Night Vision Goggles for Traversing Off-road Terrain on Foot

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The performance of humans who traversed off-road terrain while wearing monocular, biocular, and binocular night vision goggles was examined. The difficulties that each of 35 male participants encountered while walking through rough terrain and wearing the three types of goggles were scored by independent observers. Participants themselves also rated several qualities of the goggles and ranked the goggles overall. In general, results indicated that the binocular goggle yielded better performance and was preferred to the other two goggles and that the biocular and the monocular goggles showed no consistent difference for any of the four sets of dependent measures.

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A COMPARISON OF MONOCULAR, BIOCULAR, AND BINOCULAR NIGHT VISION GOGGLES FOR TRAVERSING OFF-ROAD TERRAIN ON FOOT

INTRODUCTION

Foot travel across off-road terrain at night is an important part of many military and civilian operations. At night, however, it is difficult for a human with unaided vision to see terrain features such as cliffs, berms, holes, and gullies. These terrain conditions can cause serious injury or delay when they are unseen or incorrectly perceived. Night vision goggles (NVGs) can be used to amplify the available light at night, thus allowing the observer the opportunity to perceive potential hazards. The purpose of these studies was to examine the relative performance of soldiers wearing three different ocular configurations of NVGs (monocular, biocular, and binocular) for foot travel across off-road terrain at night.

BACKGROUND

The monocular, biocular, and binocular NVGs are electro-optical devices consisting of three major parts: objective lenses, image-intensifier tubes, and eyepieces. The objective lens gathers available light and forms an image on the image-intensifier tube; the image is amplified by the image-intensifier tube, and the eyepiece magnifies the intensified image so that objects are presented at unity magnification.

The monocular, biocular, and binocular goggles differ in the following ways that are relevant to the present studies. The monocular goggle has one objective lens, one image-intensifier tube, and one eyepiece. An observer who uses this device at night would see an intensified view of the scene in one eye and an unaided view of the scene in the other eye. The biocular goggle has one objective lens, one image-intensifier tube, and two eyepieces. Here, the observer's two eyes see the same two-dimensional (2D) intensified image of the scene, with no depth cues provided by binocular disparity. The binocular goggle has two objective lenses, two image-intensifier tubes, and two eyepieces. Unlike the biocular goggle, the binocular goggle creates two separate image-intensified views of the world from two horizontally separated viewpoints. This difference between the viewpoints results in binocular disparity between the left eye and the right eye retinal images, which for those with normal binocular vision, can provide strong cues for stereoscopic depth perception of terrain contour and other hazards.

A review of basic research in visual perception would suggest that the best ocular configuration for visually directed behavior is the binocular goggle. When stereoscopic depth information is available to the viewer, object detection and recognition performance have been shown to be superior to the level of performance obtained with monocular displays or with other types of displays that do not provide stereoscopic depth cues (Getty, 1981; Yeh & Silverstein, 1990). The improvement is attributed to (a) the increase in saliency and distinctiveness of objects that result when more information about the properties of the object is available for human observation and (b) the enhanced separation of the figure from the ground, resulting from stereopsis. In a recent study, CuQlock-Knopp and Merritt (1994) found that participants correctly identified 60% more hazardous terrain conditions when the observer's visual display provided stereoscopic depth cues than when the display provided no retinal disparity between the left and right eye images, and thus no stereoscopic depth cues.

Boff, Kaufman, & Thomas's (1986) handbook of perception and performance, a standard desk reference geared to psychologists and general human factors practitioners, also recommends that observers be provided displays that allow them to use their binocular vision. The relevant findings cited in this handbook indicate that performance is typically better with both eyes than with one eye. This binocular advantage holds true for visual acuity, detection, contrast sensitivity, and form detection.

No controlled studies were found that isolated the effects of the three ocular configurations in the applied literature, although numerous studies were found that have investigated visual performance using NVGs, the utility of NVGs, and the technological improvements that have been made in NVGs over the years (Austin, 1989; Cook & Patterson, 1991; Hadani, 1991; Boyle, 1989; Tjernstrom, 1993; Sheehy & Wilkinson, 1989; Kaiser, 1991; Rabin, 1993). These studies, although informative about NVGs in general, do not bear directly on the choice of ocular configuration.

Discussions with researchers and users of NVGs did, however, lead to awareness of informal field tests and anecdotal evidence about the relative performance of the three configurations. One recurring conjecture was that the monocular configuration has the advantage of allowing the observer to maintain dark adaptation over a wide, unbroken field of view (FOV) in the unaided eye. This redeeming attribute is believed to increase its competitiveness with the binocular goggle. The only advantage discussed for the biocular goggle is its reduced cost in comparison with the cost of the binocular goggle; the biocular goggle is about half the cost of the binocular goggle.

No discussion or study, either informal or controlled, could be found that isolated the effects of viewing the environment monocularly, biocularly, or binocularly from the effects of order, practice, and terrain-course difficulty. The present studies were designed to fill this gap in the research literature. The researchers expected that participants would perform better and prefer the binocular goggle to the other two goggles. The authors made no predictions about the relative performance of the biocular and the monocular goggles.

METHOD

Research Design

A Graeco-Latin square design was chosen to counterbalance the effects of four independent variables: goggle type, course, subject group, and order. Participants were randomly assigned to the three groups, subject to the restriction that pilots and non-pilots were balanced in each group. As shown in Figure 1, participants in Group 1 wore the biocular goggle for the first run, which was on Course C. For the second run, they wore the monocular goggle on Course B. For the third run, they wore the binocular goggle on Course A. Likewise, participants in Group 2 wore the monocular goggle first on Course A, and so forth. The entire Graeco-Latin square was completed twice each night for three successive nights of high moon illumination. Nineteen days later, the same Graeco-Latin square was repeated with a new set of participants to assess performance during three successive nights of low moon illumination. (A discussion of the difference in NVG performance during low and high moon conditions is provided in Appendix A.)

ORDER OF EXPOSURE TO THE THREE GOGGLE TYPES

	RUN 1	RUN 2	RUN 3
COURSE A	MONOC Group 2	BIOC Group 3	BINOC Group 1
COURSE B	BINOC Group 3	MONOC Group 1	BIOC Group 2
COURSE C	BIOC Group 1	BINOC Group 2	MONOC Group 3

Figure 1. The Graeco-Latin square design used for the experiments. (Groups 1, 2, and 3 are the three groups of participants used in the studies. Order denotes the sequence of exposure to the three goggles and courses. Goggles denotes goggle type--monocular, biocular, and binocular. Course denotes which of the three courses (A, B, or C) is used. The Graeco-Latin square was repeated six times for the high moon illumination experiment and six times for the low moon illumination experiment.)

Independent Variables

The independent variable for goggles had three levels: monocular, biocular, and binocular. This was the main variable of interest in these studies. The independent variables of course, group, and order were considered nuisance variables and were used in this design so that the authors could isolate the variation in performance attributable to goggle type from the variation in performance attributable to these unavoidable but irrelevant variables.

The group independent variable allowed one to assess the performance variation attributable to differences between subject groups, differences that would occur only by chance or by any effects related to specific combinations of courses, goggles, and ordering. One experiment using these independent variables was conducted during nights of high moon illumination (the average light level was 5.70×10^{-3} footcandles). A second experiment replicated the same procedures during three nights of low moon illumination (the average light level was 9.61×10^{-4} footcandles). These were comparable to 3/4 and no moon light levels, respectively.

Dependent Variables

On the basis of traversals of potential off-road test sites and discussions with users of NVGs, the authors summarized the perceptual and motor demands for the experiments as the detection and avoidance of ground-level hazards (e.g., stones, fallen logs, holes, roots, and streams); eye-level hazards (e.g., trees, branches, wires, poles, and vines); and terrain contour hazards (e.g., berms, side slopes, gullies, ditches, and drop-offs). Our dependent variables reflect this categorization. Two of these dependent variables were based on information recorded by an independent observer (denoted as the "lane walker") who followed the participant as he traversed the course. The other six dependent variables were subjective evaluations made by the participants themselves.

Dependent Variable 1

Eight types of errors were tallied by the lane walkers: (1) contact with an eye-level hazard, (2) contact with a ground-level hazard, (3) contact with a terrain contour hazard, (4) marked decrease in walking pace, (5) request for assistance, (6) stop, (7) stumble, and (8) other. Variable 1 is the total number of errors summed over all eight types made by the participant while he traversed the course.

Dependent Variable 2

The time measure is the sum of the time taken by the participant in completing each course.

Dependent Variable 3

Variable 3 is the average of the participants' ratings of each goggle over six individual items. Three of these items reflected the participant's rating of the warning afforded by the goggles in preventing his contact with eye-level, ground-level, and terrain contour hazard irregularities. The remaining three items reflected the participant's visual confidence, visual comfort, and his general feeling of the extent to which the goggles allowed timely forewarning of terrain hazards. Seven-point rating scales were used (1 was the lowest and 7 was the highest rating). These rating scales comprise Questionnaire A, which is included as Appendix B.

Dependent Variables 4 through 8

Variables 4 through 8 consist of the participants' direct rank order of preference of the three goggles. The participants first ranked the three goggles for each of four specialized aspects of goggle utility: depth perception (Variable 4), target detection, that is, detection of aids or obstacles to foot travel, (Variable 5), environmental awareness (Variable 6), and visual comfort (Variable 7). The participant next ranked the goggles based on the item, "Write 'best' under your first choice of goggles to wear during a night mission; write 'worst' under your last choice." The response to this item was Variable 8. The participant recorded his rankings on Questionnaire B, which is included as Appendix C.

Participants

Test Participants

Thirty-five male national guardsmen between the ages of 19 and 54, who were from the Attack Helicopter Battalion, Edgewood, Maryland, were used as participants. (The 36th participant failed to report for the test. This participant would have been the last participant needed to complete the twelfth replication of the Graeco-Latin square design.)

Lane Walkers

The lane walkers were all male national guardsmen. They were all trained in the use of NVGs at an NVG course at Ft. Rucker, Alabama. They were physically fit and had extensive orienteering experience through the National Guard. Each lane walker was assigned to a specific course throughout the studies reported here. The tasks of each were to instruct and aid the participant in adjusting and focusing the goggles and then to follow him as he traversed the course. While doing this, the lane walker recorded the errors made by the participant and recorded the time taken to complete the course. Each lane walker wore the aviator's night vision imaging system (ANVIS) (binocular) NVG while performing his lane-walking duties.

Interviewer

The interviewer was the person responsible for administering Questionnaires A and B to the participants.

APPARATUS

Night Vision Goggles

The three types of NVGs used for these studies are essentially identical in the characteristics of FOV (40° circular), resolution (0.8 cycle per milliradian), and magnification (1X). The binocular goggle was the AN/AVS-6 (called ANVIS). The monocular goggle was the same ANVIS but with the left tube assembly removed. (The participants had an unaided view of the terrain in the left eye and an aided view of the terrain in the right eye.) The biocular goggle was the AN/PVS-7B, approximately equal in weight to the binocular ANVIS goggle. The three types of goggles were attached to the standard aviator's helmet with the standard ANVIS mount. (For the sake of consistency, the biocular goggle was retrofitted to use the same ANVIS mount used on the binocular and monocular goggle. The battery pack for the monocular and binocular goggles was mounted on the back of the aviator's helmet. Counterweights were added to the helmets for all three types of goggles to counterbalance the front load on the helmet.) Standard AA batteries were used; batteries were replaced at the beginning of each night of testing. Figure 2 depicts the three types of goggles from the frontal view as worn by the participants on the aviator's helmets.

Test Site

The experiments were conducted at the Broad Creek Memorial Boy Scout Camp in Harford County, Maryland. The test area consisted of meadows and woods of deciduous and coniferous trees with a variety of terrain hazards to foot travel, such as drop-offs, berms, and ditches. Three different

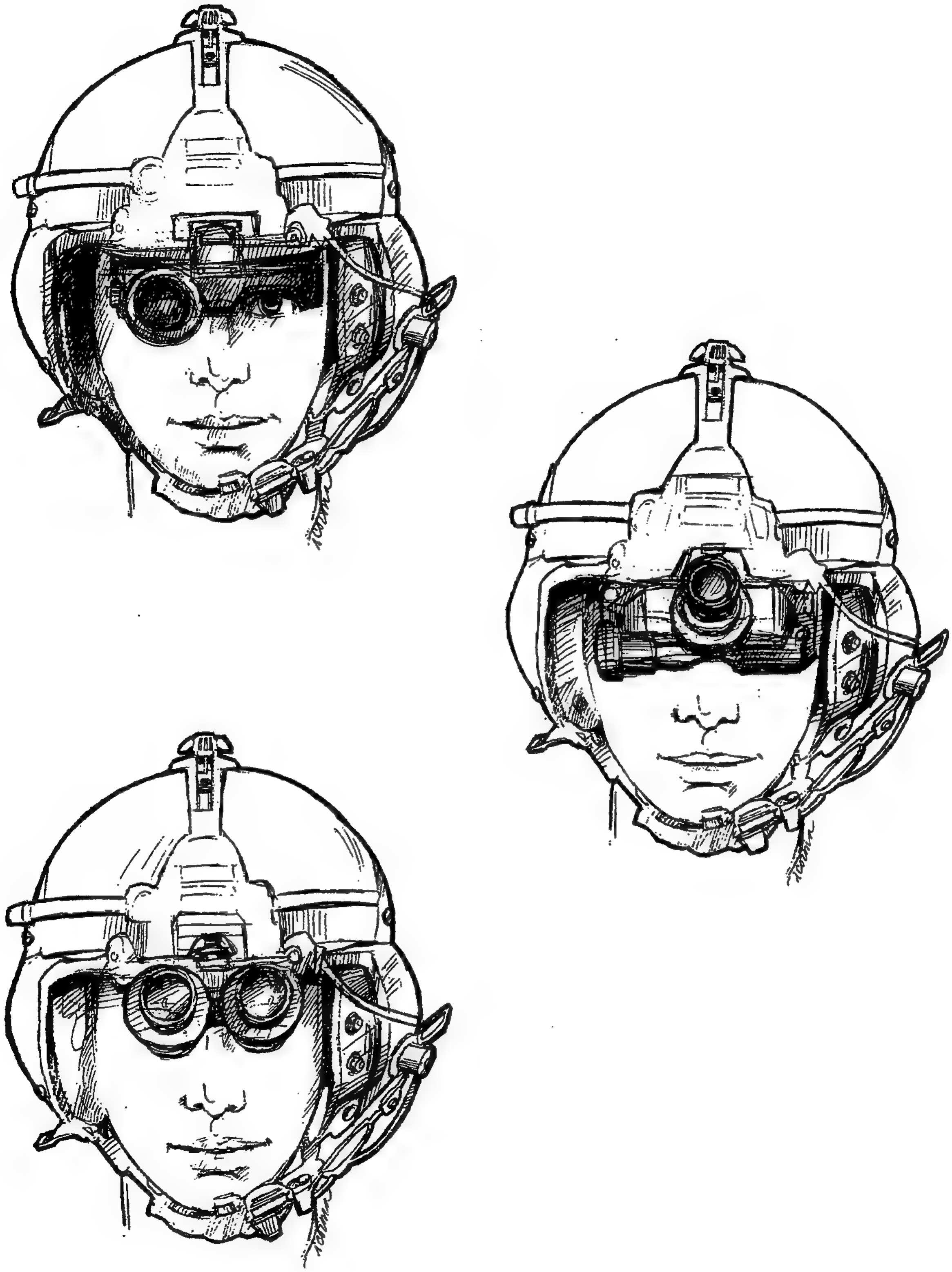

Figure 2. The helmet-mounted monocular, biocular, and binocular goggles worn by the participants.

1-kilometer courses (Course A, Course B, and Course C) were developed for the experiments. White circular plates were mounted on the trees along the course to designate the path that the participant should follow through the course. On the average, the plates were 18 feet apart. All three courses were designed to be traversed in fewer than 30 minutes at night. The courses were also designed to provide adequate changes in terrain to allow ample opportunities to check hazard-avoidance performance.

Some of the varieties of terrain are shown photographically in Figures 3 through 5. Figure 3 shows a forested area. Figure 4 is an example of sloping terrain. Figure 5 shows a low, meadow-like area.

PROCEDURES

Preliminary

The lane walkers were trained about the scoring and timing procedures used during the test. Each of the lane walkers traversed the course assigned to him in the daylight to ensure his knowledge of the terrain. The authors conducted two pilot tests to give the lane walkers extensive experience in scoring and timing the participants and to determine the adequacy of the testing procedures.

Testing Procedures

Each set of three participants began the experiment in a cabin with a level of illumination low enough to permit dark adaptation. They first read and signed a consent form and then were tested for at least 20/40 visual acuity and stereoscopic vision. The Snellen chart was used to screen for the acuity requirement, and a locally developed stereoscopic test was used to screen for the stereoscopic vision requirement. Next, the participants were shown all three goggles and informed about the purpose of the experiment and the procedures for focusing and adjusting the goggles. They were also given a safety briefing concerning traversing off-road terrain at night. Each participant then put on the type of goggle appropriate for the first run in his group assignment. At this time, the participants were given an extensive briefing about adjusting and focusing the goggles; each of the lane walkers then assisted the participants in fitting and adjusting the goggles.

Each participant then went outside where he used a second Snellen vision chart to check and readjust, if necessary, the focusing of the goggles. Next, each participant followed his lane walker to the starting point of Course A, B, or C. (Thus, there was one participant and one lane walker at the starting point of each course at this time.) The lane walker gave the direction to the participant to start traversing the course as quickly as possible. The lane walker started a stopwatch as soon as the participant took his first step, and he recorded the time taken by the participant to complete each segment of the course on a score sheet. The lane walker also noted each instance of an error (stumbles, stops, etc.) made by the participant in completing the course. (This score sheet is included as Appendix D.)

After finishing the course, the participant returned to the cabin where he completed Questionnaire A to record his subjective ratings of the goggles. He then put on his next goggle and followed his new lane walker outside to repeat the focus check using the Snellen vision chart and to begin the next course. This procedure was repeated until all three courses, along with their associated Questionnaire A forms, were completed. Following this, the participant completed Questionnaire B, the questionnaire used to rank the goggles. After this questionnaire was completed, the participant was

Figure 3. Forested terrain.

Figure 4. Sloping terrain.

Figure 5. Low meadow-like terrain.

debriefed and paid $50.00 for his services. A chart showing the sequence of events for a set of three test participants is presented in Appendix E.

Two sets of three participants were tested each night. The second set of participants began their testing immediately after all the first set of participants left the camp. Hence, six participants were tested per night. There were three successive nights of testing in this format for the 3/4 moon illumination experiment; 19 days later, there were three successive nights of testing in this format for the no-moon illumination experiment.

RESULTS

Objective Measures

Separate sets of planned orthogonal contrasts for the dependent measures were performed. The independent variables were goggle type, course, order, and groups. The comparison of main interest was the binocular NVG versus the other two NVG types. The second comparison was the monocular versus the biocular goggle. Separate planned orthogonal contrasts were run for the two levels of illumination. Tables 1 and 2 present a summary of the number of errors for each type of error recorded by the lane walkers, summed across participants. Table 1 shows the high moon illumination data, and Table 2 shows the low moon illumination data.

Table 1

Number of Errors as a Function of Goggle Type and Type of Error, 3/4 Moon Experiment

	Goggle type		
Error type	Monocular	Biocular	Binocular
Eye	31	34	24
Ground	28	31	21
Terrain	15	13	12
Slowness	21	19	13
Assistance	10	5	5
Stop	22	18	16
Stumble	12	18	10
Other	2	0	0
Total	141	138	101
Mean	7.8	7.6	5.6
N=18			

Table 2

Number of Errors as a Function of Goggle Type and Type of Error, No-Moon Experiment

Error type	Goggle type Monocular	Biocular	Binocular
Eye	30	31	32
Ground	32	30	31
Terrain	2	14	2
Slowness	15	14	7
Assistance	11	3	1
Stop	25	18	12
Stumble	14	13	7
Other	2	3	1
Total	131	126	93
Mean	7.7	7.4	5.4
N=17			

In the high moon illumination (3/4 moon) experiment, significantly fewer errors were made when the binocular goggle was worn than when the participants wore the other two types of goggles, $F\ (1,\ 45) = 5.65$, $p = .02$. There was no significant difference in performance between the biocular goggle and the monocular goggle, $F\ (1,\ 45)\ .03$, $p = .87$. Similarly, under low moon illumination (no moon), wearing the binocular goggle resulted in significantly fewer errors compared to the other two goggles, $F\ (1,\ 45) = 9.33$, $p = .004$. Again, no significant difference was found for the number of errors between the biocular and the monocular goggles, $F\ (1,\ 45) = .31$, $p = .58$.

Table 3 presents mean elapsed times in minutes for each of the three goggle types. The course time segments were summed to obtain a total elapsed time score for the entire course for each participant. The ordering of the goggles is consistent with the error data.

Planned orthogonal contrasts were also conducted for differences among the goggles in time to complete the course. The contrast analysis of goggles for the low moon illumination experiment showed a significant difference between the binocular goggle and the two other goggles $F\ (1,\ 45) = 9.06$, $p = .004$, with no statistically significant difference between the biocular and the monocular goggles $F\ (1,\ 45) = 2.47$ $p = .123$. For high moon illumination, no time differences reached significance at the 5% level (binocular versus the biocular and monocular goggles $F\ (1,\ 45) = 3.44$, $p = .07$, and biocular versus the monocular goggle $F\ (1,\ 45) = .00$ $p = .98$). The summary tables for the contrast analyses are presented in Appendices F through H.

Table 3

Mean Elapsed Times (in minutes) as a Function of Goggle Type and Amount of Moonlight

Moonlight	Goggle type Monocular	Biocular	Binocular
No moon	14.22	15.39	13.14
3/4 moon	12.76	12.74	11.86

Some of the main effects for the nuisance variables reached statistical significance at the .05 level of significance, but these rather small differences are not relevant to the purposes of the studies. The complete analysis of variance (ANOVA) tables are given in the appendices.

Participants' Evaluations

The goggles were rated on 7-point scales (1 = poor, 7 = good performance) for six qualities: the warning afforded by the goggles in preventing the participant's contact with (1) eye-level hazards, (2) ground-level hazards, (3) terrain contour hazard irregularities, (4) visual confidence, (5) visual discomfort, and (6) general feeling that the goggles allowed timely forewarning of terrain hazards. (The participants' response to Item 5 was reversed so that high ratings always correspond to better performance.) The six individual items in Questionnaire A were summed to obtain a single score for each participant for the entire questionnaire. The averages of each of the six questionnaire items for each of the goggles are shown in Figure 6.

The average of the ratings of the six qualities was analyzed using the same contrasts as used for the error and time measures. Under both the high moon and low moon illumination levels, the binocular goggle was rated significantly higher than the biocular and the monocular goggles, $F\ (1, 45) = 7.26$, $p = .01$ (high moon) and $F\ (1, 45) = 9.72$ $p = .003$ (low moon). The monocular goggle and the biocular goggle again showed no statistically significant difference in the average ratings for both the low moon and the high moon conditions, $F\ (1, 45) = .21$ $p < .652$ (3/4 moon) and $F\ (1, 45) = 1.46$ $p < .233$ (no moon).

After the participant finished his third course, he was asked to <u>rank</u> each goggle relative to the other two goggles for four aspects of goggle utility: depth perception, level of comfort, target detection, and environmental awareness. The averages, across subjects, of each of the four questionnaire items and for each type of goggles are shown in Figure 7.

One additional ranking was made to obtain the overall preferences of the participants. Figure 8 represents the response to the item "Write 'best' under your first choice of goggles to wear during a night mission; write 'worst' under your last choice." Again, the binocular goggle was preferred to the other two types of goggles and there was essentially no difference between the monocular and the biocular goggles.

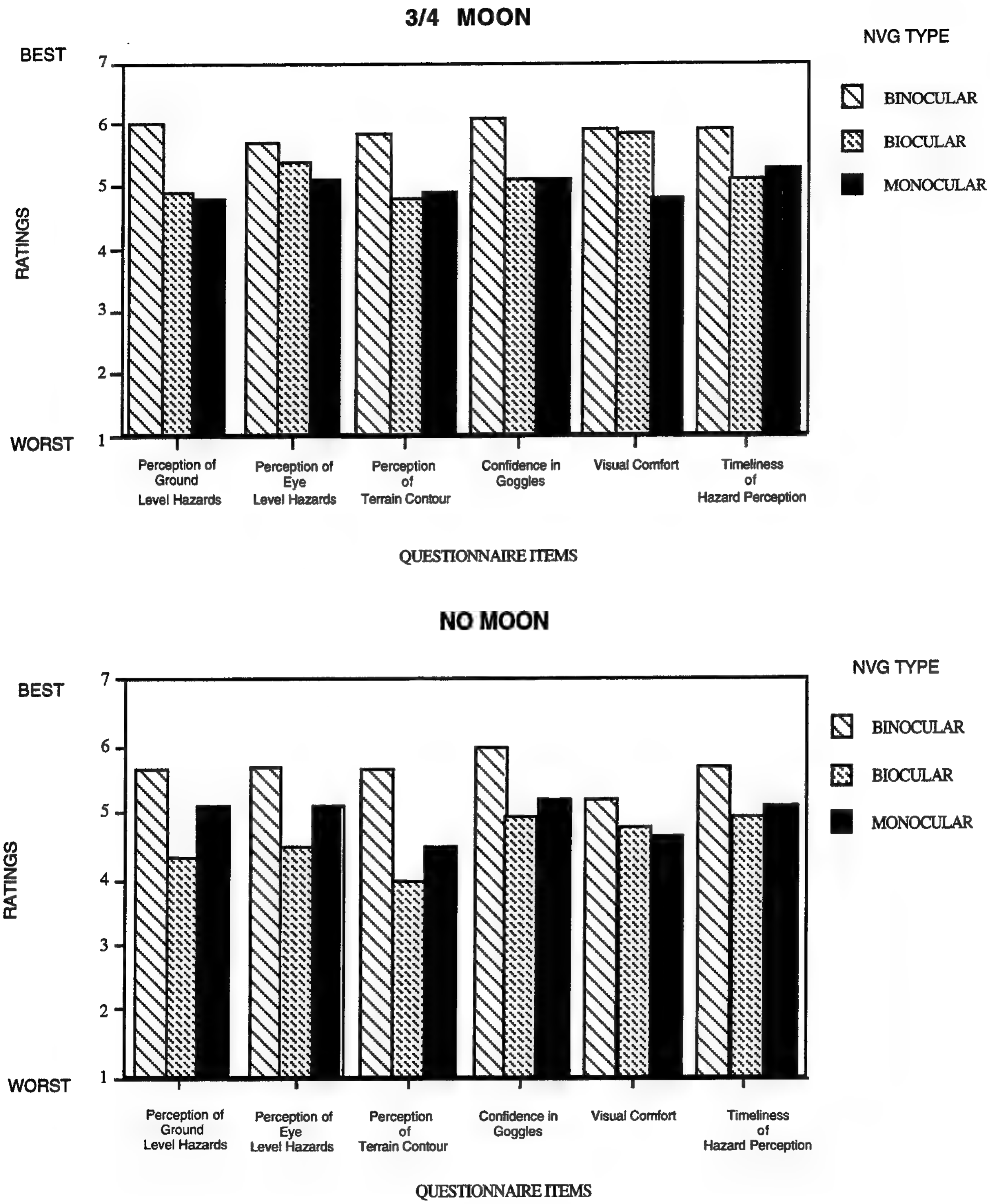

Figure 6. The average, across subjects, of each of the six Questionnaire A items for the monocular, biocular, and binocular NVGs for the 3/4 moon and no-moon experiments.

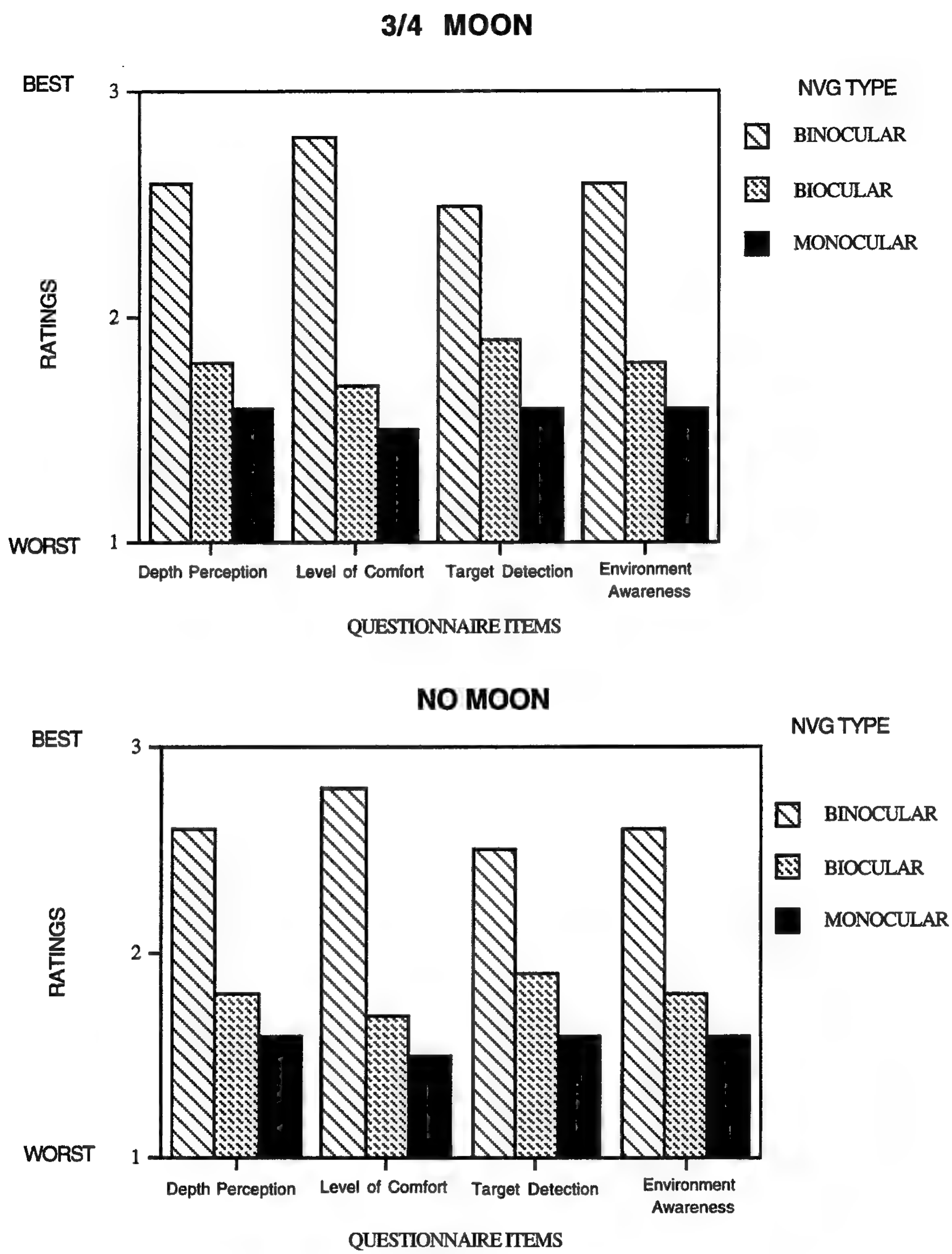

Figure 7. The average, across subjects, of each of the four Questionnaire B items for the monocular, biocular, and binocular NVGs for the 3/4 moon and no-moon experiments.

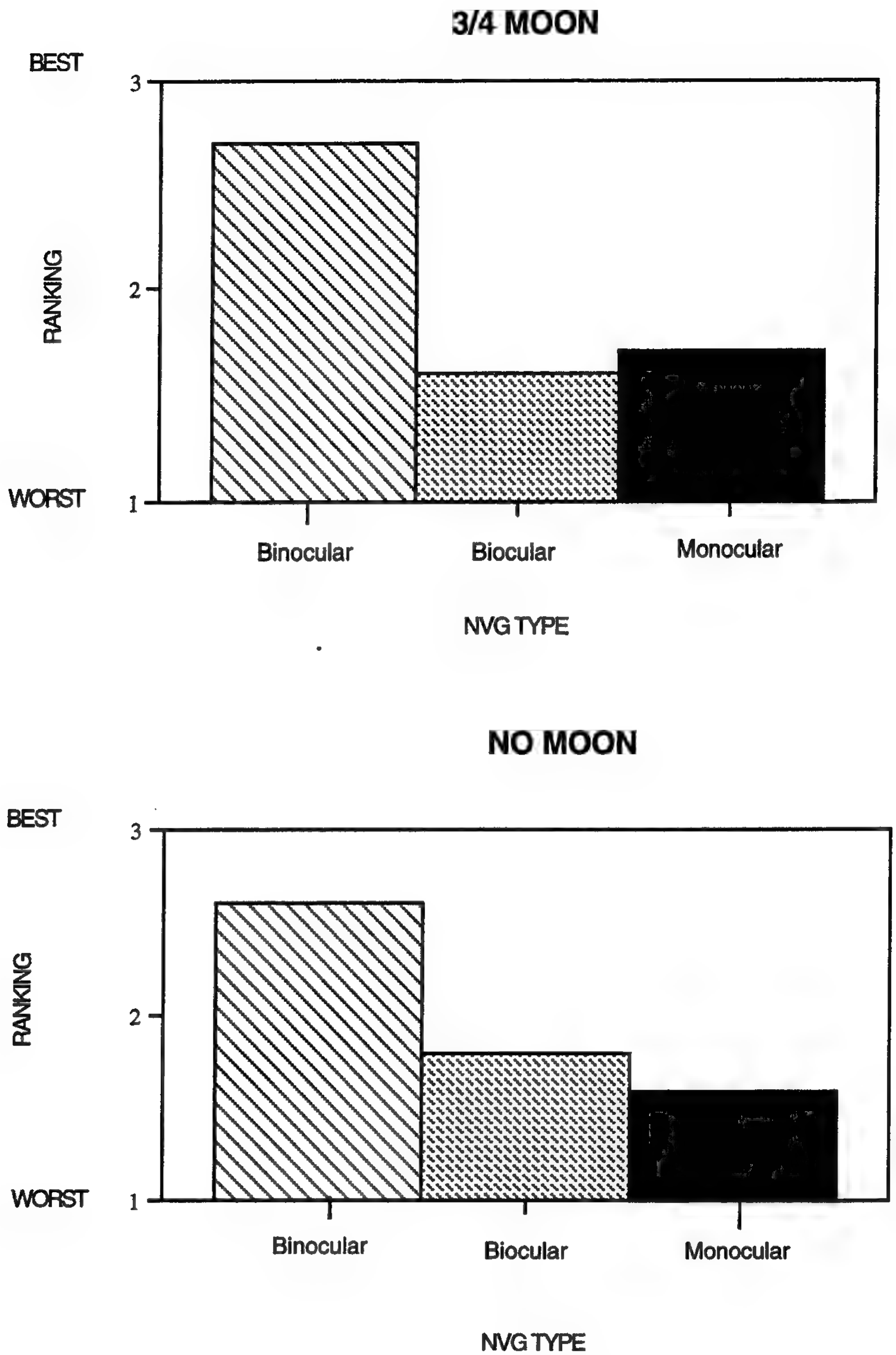

Figure 8. The response to the item, "Write 'best' under your first choice of goggles to wear during a night mission; write 'worst' under your last choice."

For both the low moon and high moon illumination experiments, each of the five rankings showed a significant effect for goggle type. The Friedman rank order ANOVAs data for each variable (Variables 4 though 8) are presented in Appendix I for the 3/4 moon experiment and Appendix J for the no-moon experiment. Again, the binocular goggle was ranked higher than the other two goggles, and there was essentially no difference between the biocular and the monocular goggles.

Finally, paired comparison data were calculated to derive the average number of times that each of the three goggles was preferred to each of the other two. These data are presented in Table 4.

Table 4

Paired Comparison Preferences of Goggle Type

Depth perception	
Binocular preferred to biocular	29 to 6
Binocular preferred to monocular	30 to 5
Monocular preferred to biocular	18 to 17
Level of comfort	
Binocular preferred to biocular	30 to 5
Binocular preferred to monocular	31 to 4
Monocular preferred to biocular	19 to 16
Target detection	
Binocular preferred to biocular	23 to 12
Binocular preferred to monocular	31 to 4
Monocular preferred to biocular	23 to 12
Environmental awareness	
Binocular preferred to biocular	25 to 10
Binocular preferred to monocular	30 to 5
Monocular preferred to biocular	18 to 17

DISCUSSION

Results of these studies indicated that participants moved faster and made fewer errors (e.g., stops, stumbles, contacts with ground-level hazards) with the binocular NVG than with the other two types of goggles. They also preferred the binocular goggle to the biocular and monocular goggles. In general, there was no consistent, statistical difference between the biocular and the monocular goggles.

The error data indicate that when the participants wore the binocular goggle, they made 40% fewer errors in general (summed across error type) than when they wore the monocular goggle and 36% fewer errors than when they wore the biocular goggle. The participants made almost the same number of errors wearing the monocular goggle as wearing the biocular goggle.

Time differences among the goggles, although significant during the no-moon experiment, were not quite as marked as the differences among the means for the error data. When the participants wore the binocular goggle, they were 8% faster in general than when they wore the monocular goggle and 13% faster than when they wore the biocular goggle. The participants moved at about the same pace when wearing either the monocular goggle or the biocular goggles.

The figures that depict the participants' ratings and those that depict the participants' ranking of the three goggles, all show a similar pattern: the binocular goggle is consistently rated and ranked higher than the biocular and monocular goggles. Although the monocular and biocular goggles change ordering for some of the various aspects of goggle utility, the rating and ranking of these two goggles were always substantially below those of the binocular goggle.

Moon illumination, in general, did not affect the ordering of the goggles on the dependent measures. Although one of the differences failed to reach statistical significance during high moon illumination, the basic ordering was consistent: the binocular goggle was superior to the other two, and there was essentially no difference between the monocular and the biocular goggles.

The variables of order, course, and group did reach statistical significance for some of the dependent measures during high and low moon illumination, but these differences are not relevant for the purposes of the experiments. They were included in the experimental design to isolate the variation in goggles from the variation attributable to these nuisance variables.

Some concern has been expressed about the participant population used in these studies because half of the participants were aviators who may have previously used the binocular goggle, and thus may have had a bias in favor of that goggle. None of the aviators had experience using NVGs for <u>foot travel</u> across off-road terrain, however. Even so, two additional analyses were performed to examine the validity of this concern.

The correlation between the amount of goggle experience, from Questionnaire B, Item 6, and goggle preference, from Questionnaire B, Item 5, was computed and found to be not significantly different from zero ($r = .04$). The amount of goggle experience was unrelated to preference. In addition, paired comparison data, shown in Table 5 were retabulated for participants categorized into three groups, according to the amount of experience with goggles.

This tabulation, given in Table 6, shows that there was an increase in preference for the biocular goggle over the monocular goggle with an increase in experience, but the binocular goggle remained the preferred goggle. Hence, the original results cannot reasonably be attributed to previous experience with goggles.

Table 5

Paired Comparison Preference of Goggle Type by Experience

	Goggle experience		
	None	1 to 4 Times	> 5 Times
Binocular preferred to biocular	7 to 5	10 to 1	7 to 5
Binocular preferred to monocular	9 to 3	11 to 0	11 to 1
Monocular preferred to biocular	10 to 2	4 to 7	4 to 8

The superiority of the binocular configuration for the task used in these studies was consistent across all measures. However, the task used did not really require much reliance on peripheral vision. For the monocular configuration, the unaided eye remains in a dark-adapted state. It could be argued that this dark-adapted state might allow monocular goggle participants to use wide field peripheral vision in the unaided eye. By contrast, the light-adapted state in the central 40° FOV of the two eyes of the biocular and binocular goggles' participants may restrict acquisition of important peripheral information. Therefore, a monocular configuration might conceivably show greater utility with a task that requires peripheral vision, which might then lead to an increase in both subjective preference levels and performance.

In addition, the participants in the present studies had little if any experience in using goggles in nighttime movement on foot. It has been proposed that perhaps adequate performance with a monocular configuration could be acquired through experience. It again could be argued that individuals are not accustomed to coordinating motor behavior with a view of the world that is vastly different in luminance between the two eyes and must therefore acquire the ability to function with such disparate input. Once they learn, however, observers might then prefer a monocular configuration, perhaps because the configuration provides an unobstructed, wide field of peripheral vision in the unaided eye.

These two concerns will be addressed in two future experiments. Nevertheless, the conclusion of the present studies is clear. Given the conditions of the experiments as reported here (course length, terrain type, participant population, and the participants' task), the binocular goggle is clearly superior to the other two for both the objective and the subjective measures. Differences between the biocular and monocular goggles were small, inconsistent, and neither statistically significant nor substantively different.

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APPENDIX A

MOON ILLUMINATION AND NVG PERFORMANCE

MOON ILLUMINATION AND NVG PERFORMANCE

Image intensifiers operate by amplifying visible and near-infrared radiation which is reflected off objects in the scene. Natural forms of this radiation include moonlight, starlight, and sky glow. At low scene illumination (e.g., no moon), the relatively low signal to the intensifier results in a grainy image with noticeable scintillations (i.e., bright sparkles); this image, however, is about 2,000 times brighter than the scene would appear to the unaided eye. As illumination levels increase, the graininess and scintillations become steadily less apparent because of the increasing signal. The image, in turn, correspondingly increases in brightness so that the approximate 2000X amplification factor is maintained. At approximately quarter-moon illumination, the average image brightness reaches a maximum level set by the intensifier's power supply. As illumination increases from this point, graininess and scintillations continue to diminish because of increasing signal, but the average brightness remains constant. This trend continues for illuminations until twilight conditions.

Throughout all these illuminations, scene contrast is determined exclusively by the specific reflectances of terrain features and by the amount of shadowing; image contrast, in turn, maintains a fixed relationship to the scene contrast. Perception of fine detail is limited primarily by graininess and scintillations at low illumination, and by scene contrast at high illuminations. Aided visual acuity typically increases smoothly from 20/120 at the lowest natural scene illumination (e.g., starlight under forest canopy), to 20/40 at full moon conditions.

APPENDIX B

QUESTIONNAIRE A

QUESTIONNAIRE A

On the following scales, circle the number that best represents your response.

Rate how well the goggles performed in helping you to see ground-level hazards such as stones, fallen logs, holes, roots, and streams.

1 2 3 4 5 6 7
(no forewarning) (timely warning)

Rate how well the goggles performed in helping you to see eye-level hazards such as trees, branches, wires, poles, and vines.

1 2 3 4 5 6 7
(no forewarning) (timely warning)

Rate how well the goggles performed in helping you to see terrain contour hazards irregularities such as berms, side slopes, gullies, ditches, and cliffs.

1 2 3 4 5 6 7
(no forewarning) (timely warning)

Rate how confident you felt walking around while wearing the goggles.

1 2 3 4 5 6 7
(hesitant) (confident)

Indicate how much visual discomfort (eye strain, blurred vision, etc.) you experienced with the goggles.

1 2 3 4 5 6 7
(none) (continuous)

How often did the goggles allow adequate time to avoid the terrain hazards?

1 2 3 4 5 6 7
(never) (always)

APPENDIX C

QUESTIONNAIRE B

QUESTIONNAIRE B

A Comparison Among the Three Goggles

Write "best" under the best of the three goggles; write "worst" under the worst of the three goggles on the following qualities.

	ANAVS6 Binocular	ANPVS7 Biocular	ANAVS6 (one tube) Monocular
(1) Depth Perception	______	______	______
(2) Level of Comfort	______	______	______
(3) Target Detection	______	______	______
(4) Environmental Awareness	______	______	______

(5) Write "best" under your first choice of goggles to wear during a night mission; write "worst" under your last choice.

	ANAVS6 Binocular	ANPVS7 Biocular	ANAVS6 (one tube) Monocular
Choices	______	______	______

(6) For each time frame, write the number of times you wore night vision goggles; enter zero if you did not wear goggles during the time frame.

__ I wore goggles in October 1993.

__ I wore goggles in September 1993.

__ I wore goggles within the last year but not since August 1993.

__ I wore goggles more than 1 year ago.

(7) Write any additional comments about the strong points or shortcomings of the different goggles or problems that are common to all three goggles.

(Use the other side of the page if necessary.)

APPENDIX D

LANE WALKER'S SCORE SHEET

CONTACT WITH EYE-LEVEL HAZARD	CONTACT WITH GROUND-LEVEL HAZARD
CONTACT WITH TERRAIN CONTOUR HAZARD	MARKED 50% DECREASE IN WALKING PACE. 
REQUEST FOR ASSISTANCE	
STUMBLE	OTHER

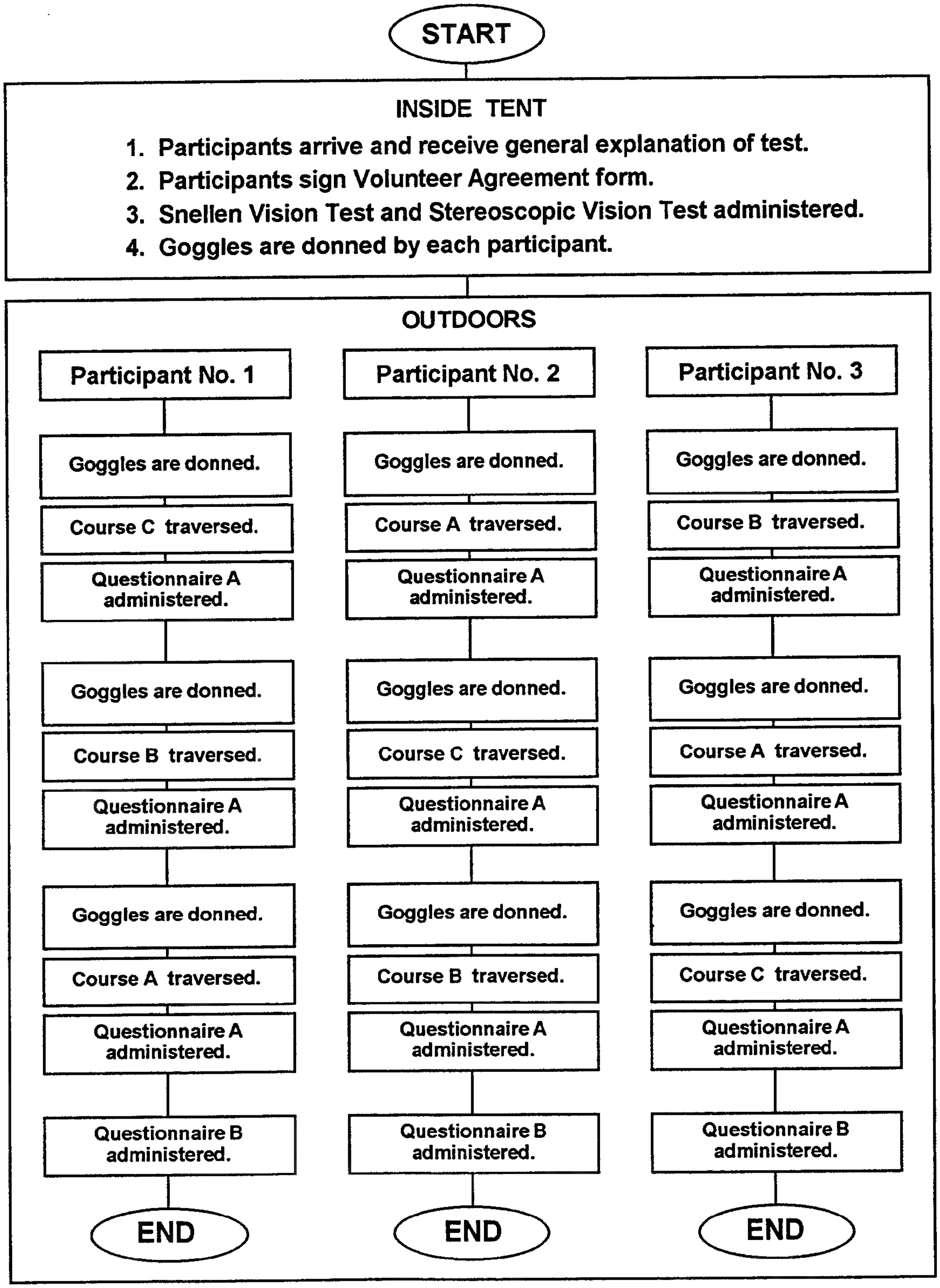
COURSE ____ GOGGLES ____ MOONLIGHT ____ GROUP ______ PARTICIPANT ______

TIME __________ TIME __________ TIME __________ TIME __________

APPENDIX E

TEST SEQUENCE

SEQUENCE OF TEST SESSION



APPENDIX F

ANALYSIS OF VARIANCE
(ERROR SCORES)

ANALYSIS OF VARIANCE
(ERROR SCORES)

Tests of Significance for ERROR SCORES Using UNIQUE Sums of Squares (3/4 Moon Illumination)

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN CELLS	437.00	45	9.71		
GROUP	16.59	2	8.30	.85	.432
ORDER	1.04	2	.52	.05	.948
COURSE	352.15	2	176.07	18.13	.000
*GOGGLE (1)	54.90	1	54.90	5.65	.022
*GOGGLE (2)	.25	1	.25	.03	.873

Tests of Significance for ERROR SCORES Using UNIQUE Sums of Squares (No Moon Illumination)

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN CELLS	345.73	45	7.68		
GROUP	9.93	2	4.96	.65	.529
ORDER	5.85	2	2.93	.38	.685
COURSE	681.57	2	340.78	44.36	.000
*GOGGLE (1)	71.70	1	71.70	9.33	.004
*GOGGLE (2)	2.35	1	2.35	.31	.583

*GOGGLE (1) is the contrast of the binocular goggle versus the unit of the biocular and the monocular goggles.

*GOGGLE (2) is the contrast of the biocular and the monocular goggles.

APPENDIX G

ANALYSIS OF VARIANCE
(TIME SCORES)

ANALYSIS OF VARIANCE
(TIME SCORES)

Tests of Significance for ELAPSED TIME Using UNIQUE Sums of Squares (No Moon)

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN CELLS	755525.20	45	16789.45		
GROUP	40568.76	2	20284.38	1.21	.308
ORDER	57310.14	2	28655.07	1.71	.193
COURSE	443220.96	2	221610.48	13.20	.000
*GOGGLE (1)	152145.12	1	152145.12	9.06	.004
*GOGGLE (2)	41425.82	1	41425.82	2.47	.123

Tests of Significance for TIME Using UNIQUE Sums of Squares
(High Moon)

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN CELLS	448533.17	45	9967.40		
GROUP	521616.00	2	260808.00	26.17	.000
ORDER	68260.11	2	34130.06	3.42	.041
COURSE	122600.11	2	61300.06	6.15	.004
*GOGGLE (1)	34240.08	1	34240.08	3.44	.070
*GOGGLE (2)	8.03	1	8.03	.00	.977

*GOGGLE (1) is the contrast of the binocular goggle versus the unit of the biocular and the monocular goggles.

*GOGGLE (2) is the contrast of the biocular and the monocular goggles.

APPENDIX H

ANALYSIS OF VARIANCE
(QUESTIONNAIRE A)

ANALYSIS OF VARIANCE
(QUESTIONNAIRE A)

Tests of Significance for QUESTIONNAIRE A Using UNIQUE Sums of Squares (3/4 Moon Illumination)

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN CELLS	1756.67	45	39.04		
GROUP	46.70	2	23.35	.60	.554
ORDER	84.93	2	42.46	1.09	.346
COURSE	102.93	2	51.46	1.32	.278
*GOGGLE (1)	283.56	1	283.56	7.26	.010
*GOGGLE (2)	8.03	1	8.03	.21	.652

Tests of Significance for QUESTIONNAIRE A Using UNIQUE Sums of Squares (No Moon)

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN CELLS	1534.83	45	34.11		
GROUP	92.80	2	46.40	1.36	.267
ORDER	45.17	2	22.58	.66	.521
COURSE	59.74	2	29.87	.88	.424
*GOGGLE (1)	331.45	1	331.45	9.72	.003
*GOGGLE (2)	49.94	1	49.94	1.46	.233

*GOGGLE (1) is the contrast of the binocular goggle versus the unit of the biocular and the monocular goggles.

*GOGGLE (2) is the contrast of the biocular and the monocular goggles.

APPENDIX I

FRIEDMAN TWO-WAY ANOVA OF QUESTIONNAIRE B (3/4 MOON)

QUESTIONNAIRE B: 3/4 MOON

Friedman Two-Way ANOVA

Mean Rank for Depth Perception

Binocular	2.72
Biocular	1.56
Monocular	1.72

Cases	Chi-Square	D.F	Significance
18	14.3333	2	.0008

Mean Rank for Level of Comfort

Binocular	2.72
Biocular	1.67
Monocular	1.61

Cases	Chi-Square	D.F	Significance
18	14.1111	2	.0009

Mean Rank for Target Detection

Binocular	2.61
Biocular	2.06
Monocular	1.33

Cases	Chi-Square	D.F	Significance
18	14.7778	2	.0006

Mean Rank for Environmental Awareness

Binocular	2.56
Biocular	1.72
Monocular	1.72

Cases	Chi-Square	D.F	Significance
18	8.3333	2	.0155

Mean Rank Preference for a Night Mission

Binocular	2.56
Biocular	1.83
Biocular	1.61

Cases	Chi-Square	D.F	Significance
18	8.7778	2	.0124

APPENDIX J

FRIEDMAN TWO-WAY ANOVA OF QUESTIONNAIRE B (NO MOON)

FRIEDMAN TWO-WAY ANOVA OF QUESTIONNAIRE B (NO MOON)

QUESTION B: NO MOON

Friedman Two-Way ANOVA

Mean Rank for Depth Perception

Binocular	2.65
Biocular	1.76
Monocular	1.59

Cases	Chi-Square	D.F	Significance
17	10.9412	2	.0042

Mean Rank for Level of Comfort

Binocular	2.76
Biocular	1.71
Monocular	1.53

Cases	Chi-Square	D.F	Significance
17	15.1765	2	.0005

Mean Rank for Target Detection

Binocular	2.47
Biocular	1.94
Monocular	1.59

Cases	Chi-Square	D.F	Significance
17	6.7059	2	.0350

Mean Rank for Environmental Awareness

Binocular	2.59
Biocular	1.85
Monocular	1.56

Cases	Chi-Square	D.F	Significance
17	9.5588	2	.0084

Mean Rank Preference for a Night Mission

Binocular	2.59
Biocular	1.76
Biocular	1.65

Cases	Chi-Square	D.F	Significance
17		2	.00